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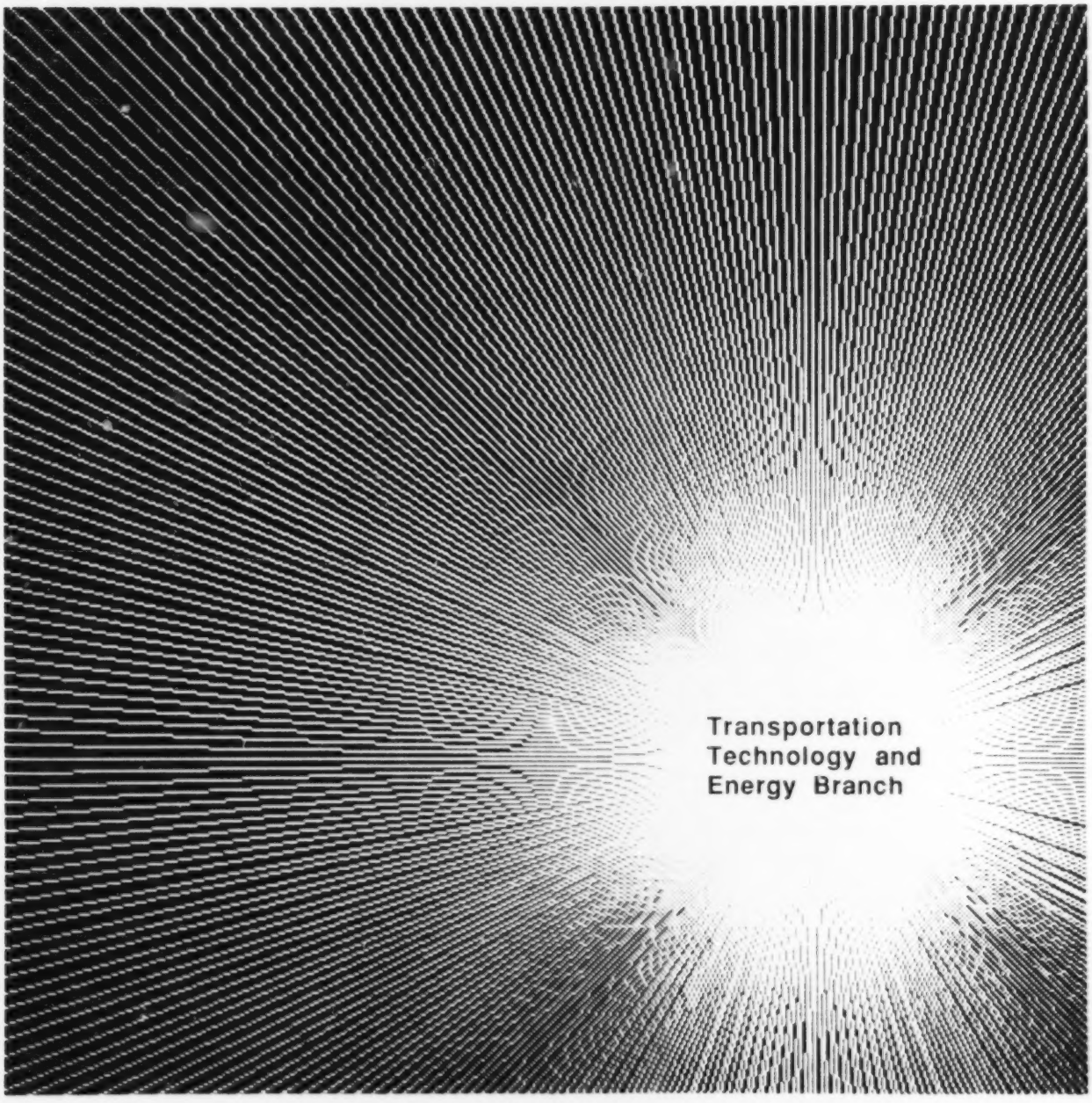

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Ontario's
Natural Gas Bus Program

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Ontario's Natural Gas Bus Program

T. Topaloglu
Head, Automotive Energy Section
Vehicle Technology Office

Presentation to
The 8th Annual
Natural Gas Vehicle Conference
Washington, D.C.
September 17-19, 1990

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Ministry of Transportation of Ontario
Room 321, Central Building
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Canada M3M 1J8
(416) 235-3466

November 1990

ONTARIO'S
NATURAL GAS BUS PROGRAM

The 8th Annual
Natural Gas Vehicle Conference
Washington, D.C.
September 17-19, 1990

Dr. Toros Topaloglu
Head, Automotive Energy Section

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Scope of Natural Gas Bus Program

BUS

- Design, develop and test an environmentally superior, safe and cost-effective NGV bus
- Deliver 50 production NGV buses to Toronto, Hamilton and Mississauga

FUELLING STATION

- Design and commission three prototype fuelling stations to meet fast-fill and slow-fill requirements of large bus fleets

GARAGE

- Assess safety risks in three Ontario garages
- Implement physical and operational improvements

History of Program

- Active, Hands-on Alternative Fuels Research, Development and Demonstration since 1975
- Propane Bus Demonstration in 1983-1988
- Natural Gas Bus Demonstration since 1985
- Natural Gas Engine Development since 1985
- Natural Gas Bus Development since 1988

BUS

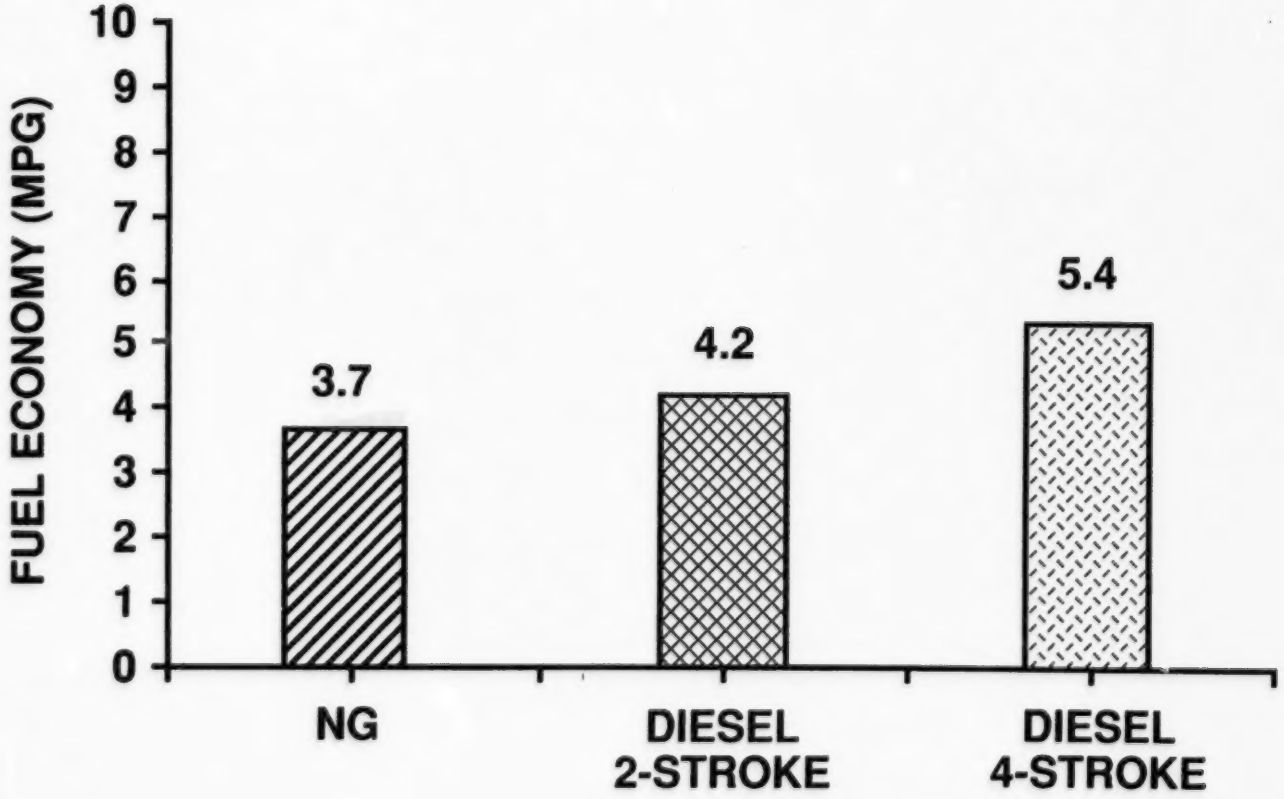
Characteristics

- 40-ft ORION
- Cummin L10-NG engine
- 200 ~ 240 HP, 700 ~ 750 ft-lb
- Oxidation catalyst
- 14,000 scf NGV storage on roof
- 400 mile range

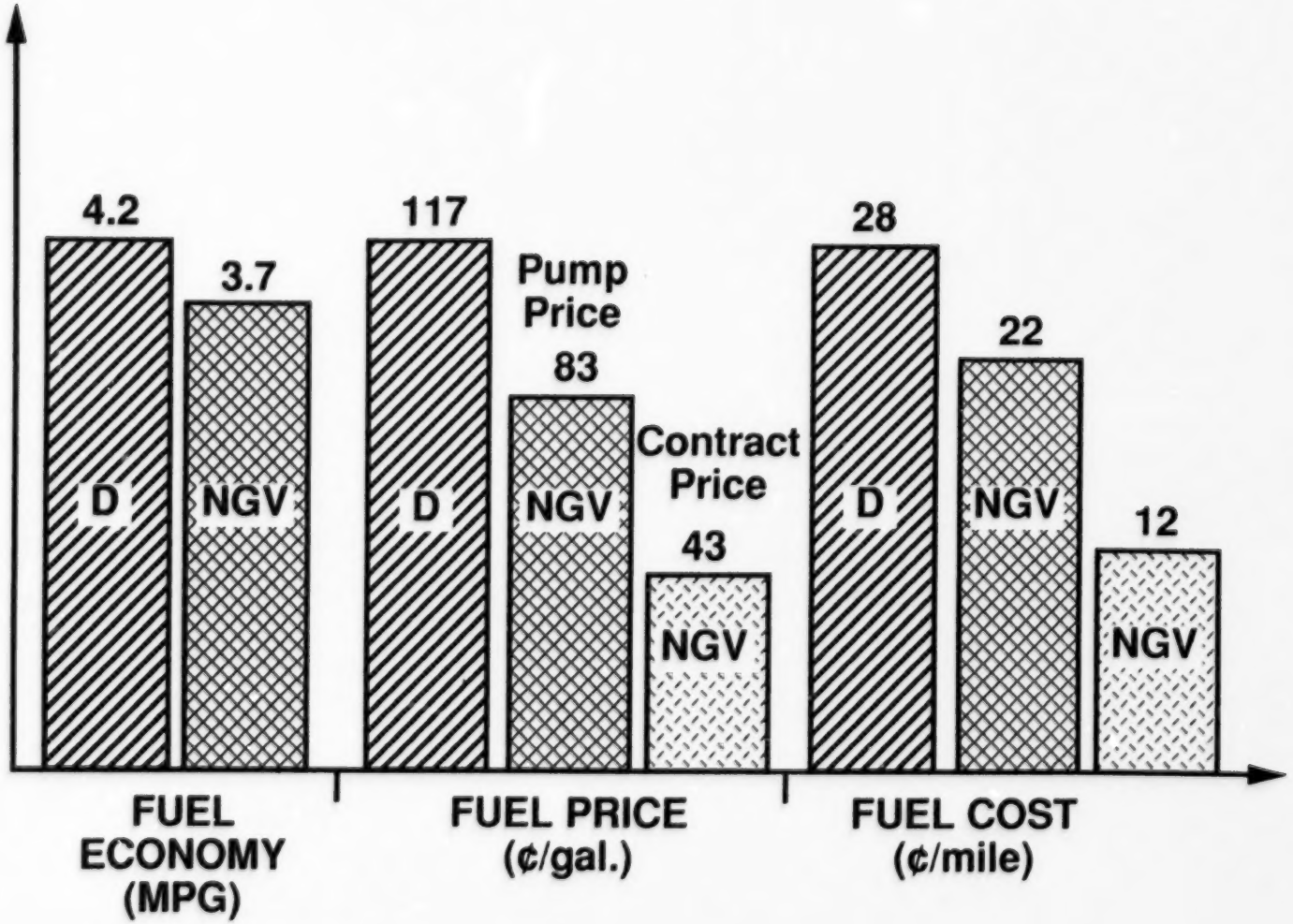
Status

- Design qualification results
  - Handling
  - Durability
  - Crash resistance
- In-service evaluation results with 4 prototype ORIONS
  - Reliability
  - Driver and public acceptance
  - Fuel consumption
- Exhaust emissions
- Noise
- Fuelling cost
- Delivery schedule of 50 buses

Fuel Economy Comparison



Bus Fuelling Cost Comparison
(Ontario Data in US Units)



FUELLING STATION

Fuelling Station Options

	Toronto	Mississauga	Hamilton
Compressors	4 x 550 scfm	2 x 250 scfm	2 x 200 scfm
Flow capacity (scfm)	2,200	500	400
Storage capacity (scf)	30,000	–	50,000
Average fill time (2/3 fill)	4 min	8 h slow fill	slow/fast-fill
Bus handling capacity (8 hr operation)	120	25	22
Estimate capital cost ($)	2.4 M	0.6 M	0.65 M
Cost/bus ($)	20,000	24,000	29,500

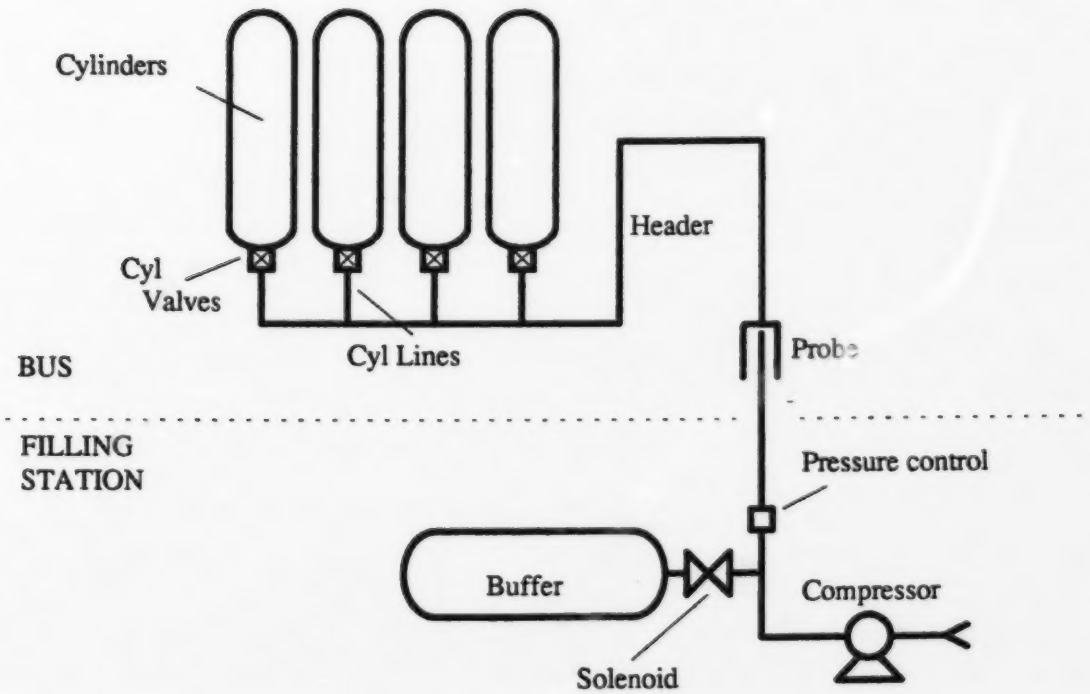
Technical Considerations

- Continuous and rapid filling of buses with CNG requires a much larger fuelling station than current practice
- Present filling systems do not allow for gas heating effect in receiving cylinders → underfilling with respect to design capacity (~15% in 5-minute fill)
- Operation of current pressure limiting devices unsatisfactory: flow restriction, poor reliability
- Over-designing not acceptable → need optimum size of lines, couplings, buffer tanks and compressors

Operational Study Results

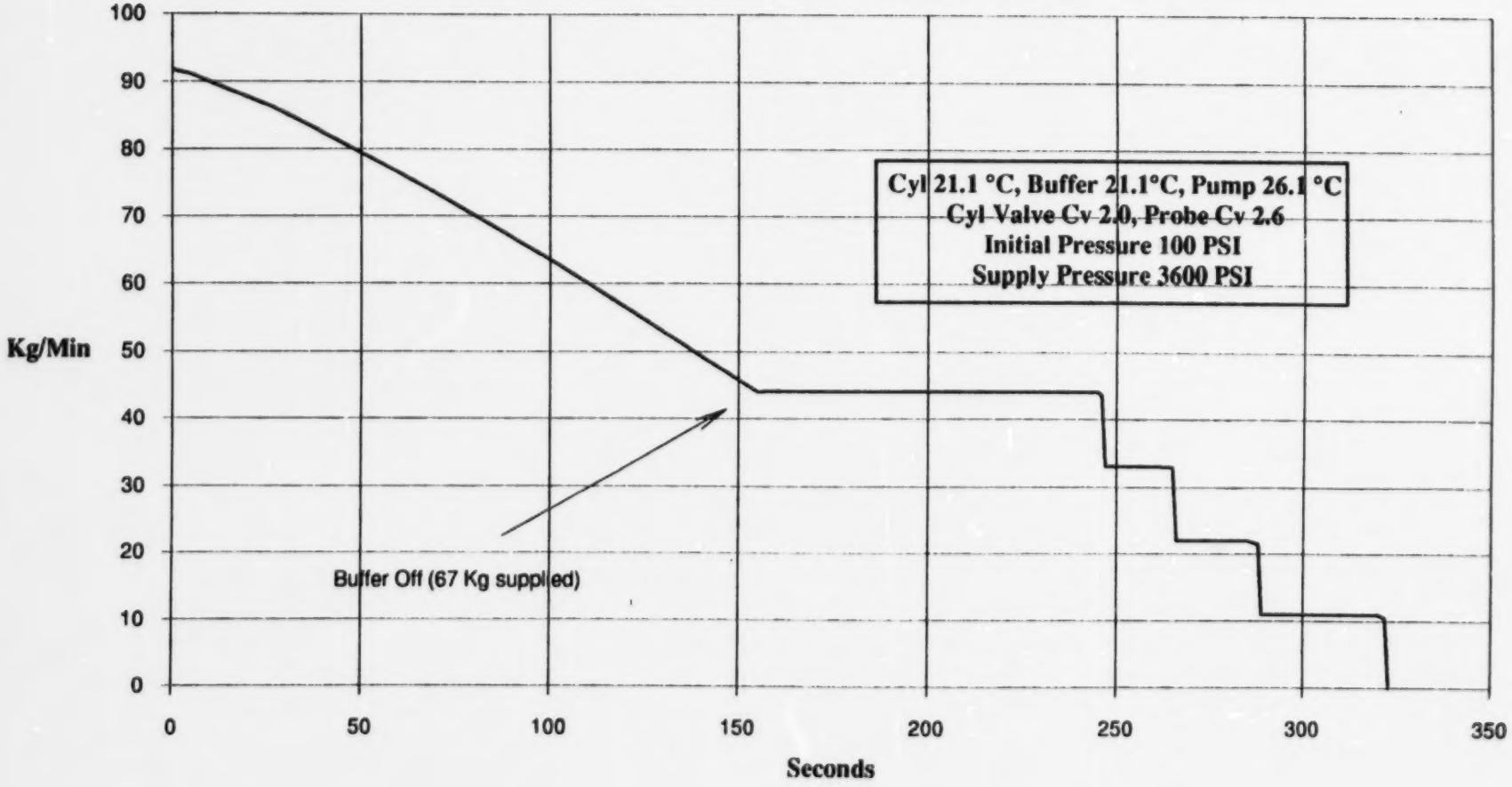
- Average diesel fuel quantity delivered: 31 U.S. gal/bus
- Maximum diesel fuel quantity delivered: 70 U.S. gal/bus
- Maximum fuel delivery rate: 19 U.S. gal/min
- Average refuelling time: 117 seconds/bus
- Average total service time: 211 seconds/bus

DIAGRAMATIC LAYOUT OF FILLING STATION AND BUS CYLINDERS

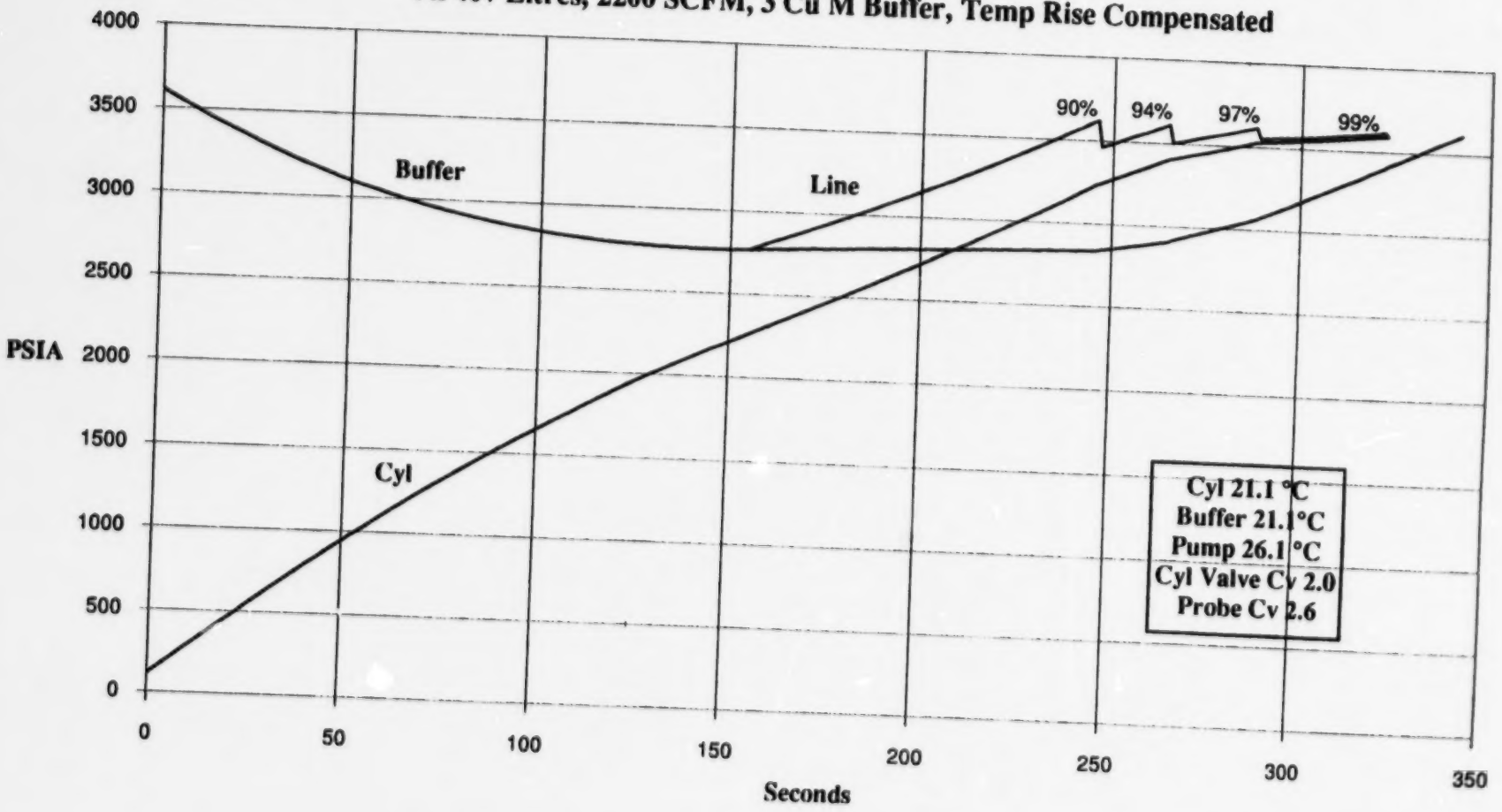


FILLING OF CNG BUS CYLINDERS

4 x 407 Litres, 2200 SCFM, 3 Cu M Buffer, Temp Rise Compensated

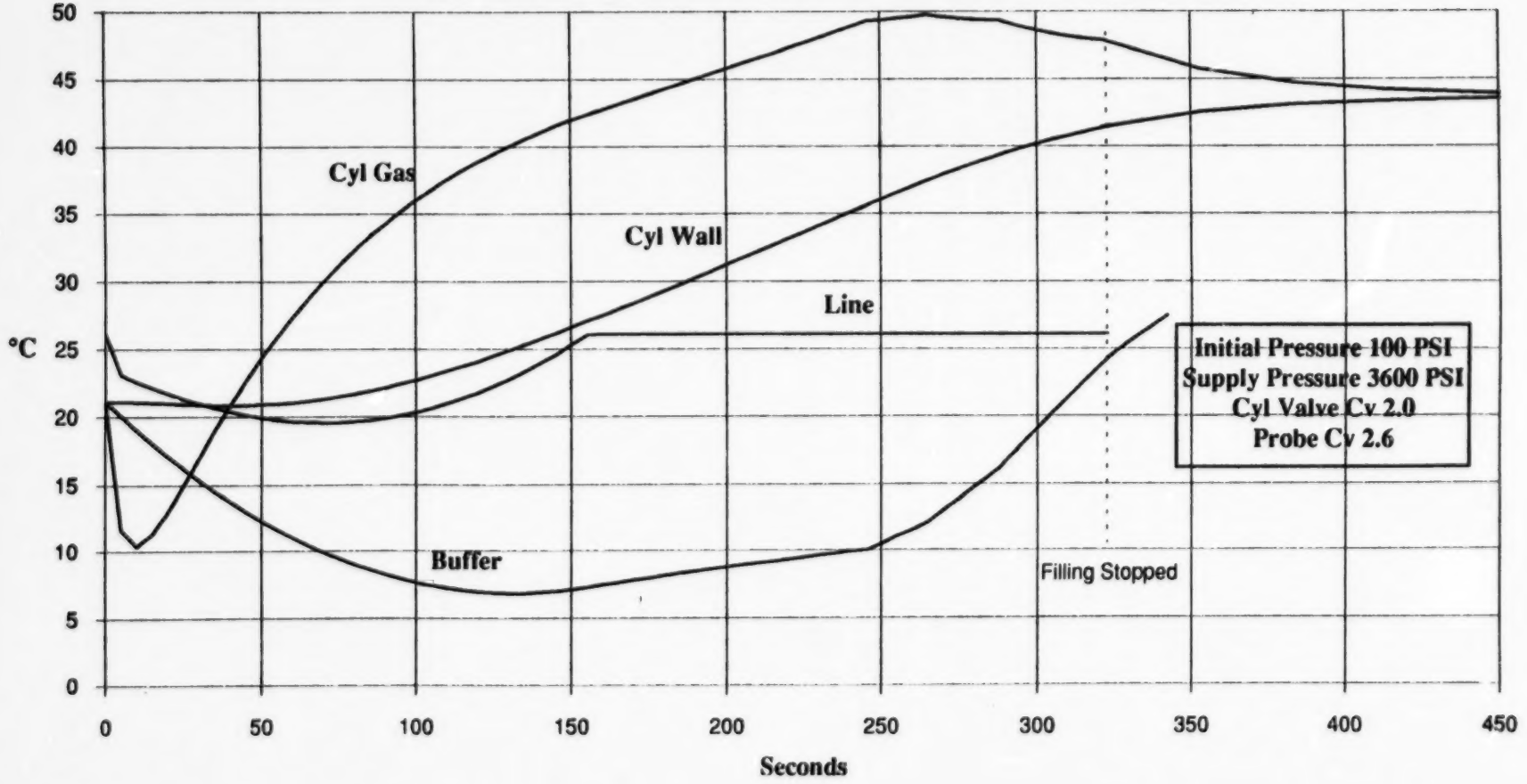


FILLING OF CNG BUS CYLINDERS



FILLING OF CNG BUS CYLINDERS

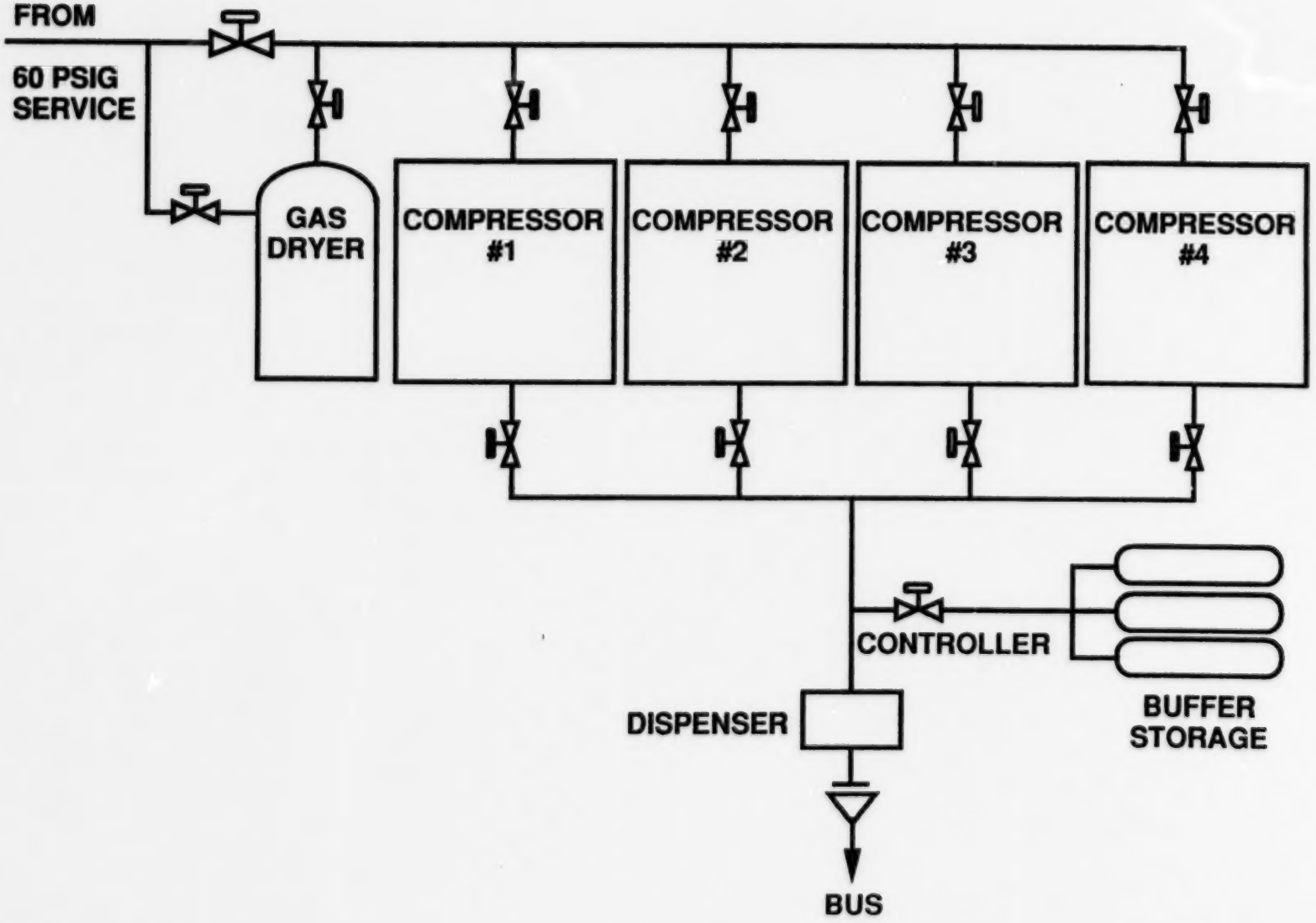
4 x 407 Litres, 2200 SCFM, 3 Cu M Buffer, Temp Rise Compensated



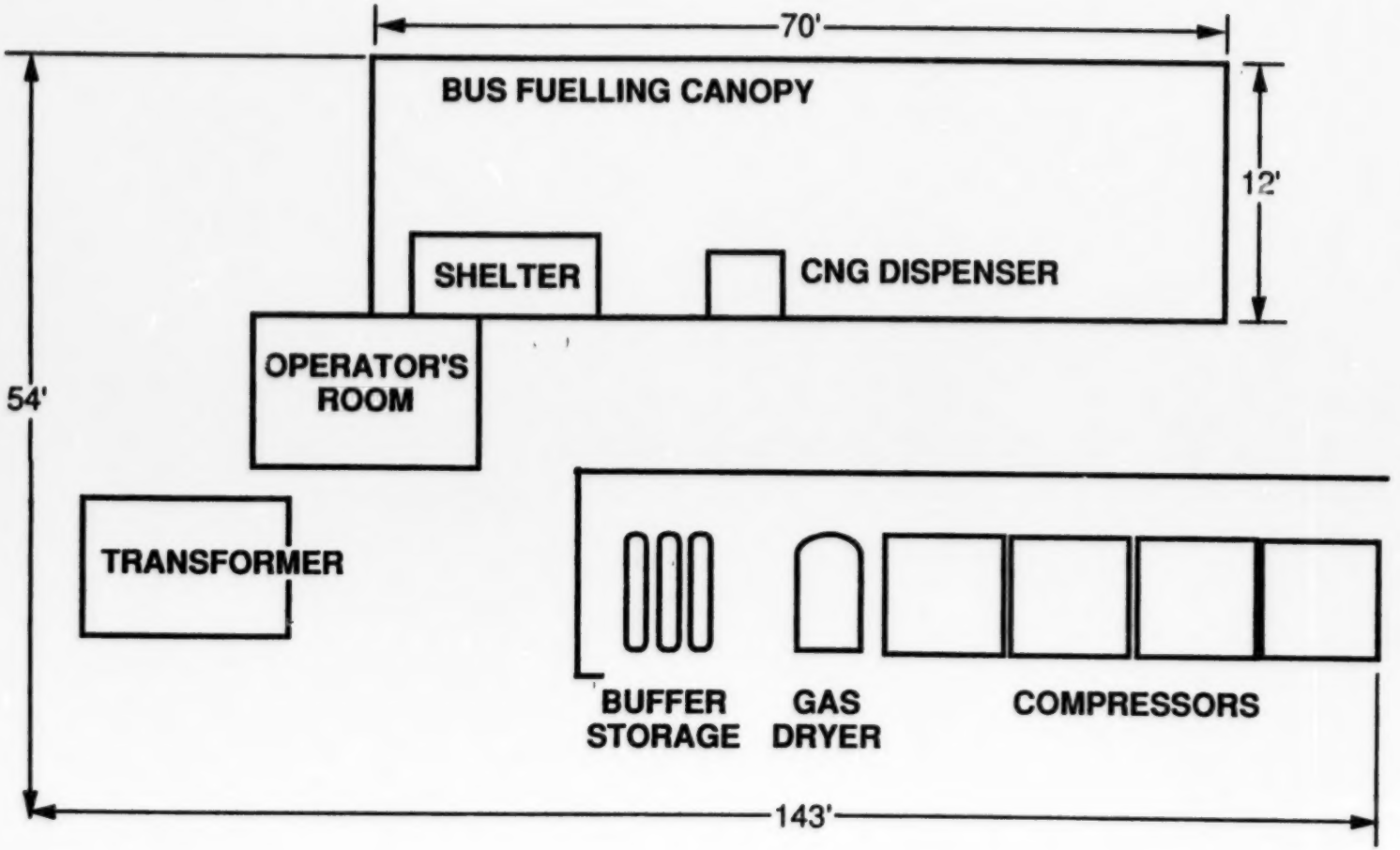
Performance Criteria

- Service up to 125 CNG buses continuously
- Deliver 8800 SCF (175 kg) of CNG within 3 min and 45 sec of connect time and 4 min service time
- Modular design with adequate redundancy (maximum compressor rating of approx. 500 SCFM at 60 psig suction)
- Safe and reliable unattended operation
- Minimize cycling
- Equalize compressor utilization
- Temperature compensation
- Prevent over pressurization
- Maintain - 40°C dew point in CNG
- Maximum sound pressure of 65 dBA at 1 m from machine envelope
- Minimum maintenance and space, maximum efficiency and flexibility

Fuelling Station Schematic



Fuelling Station Layout

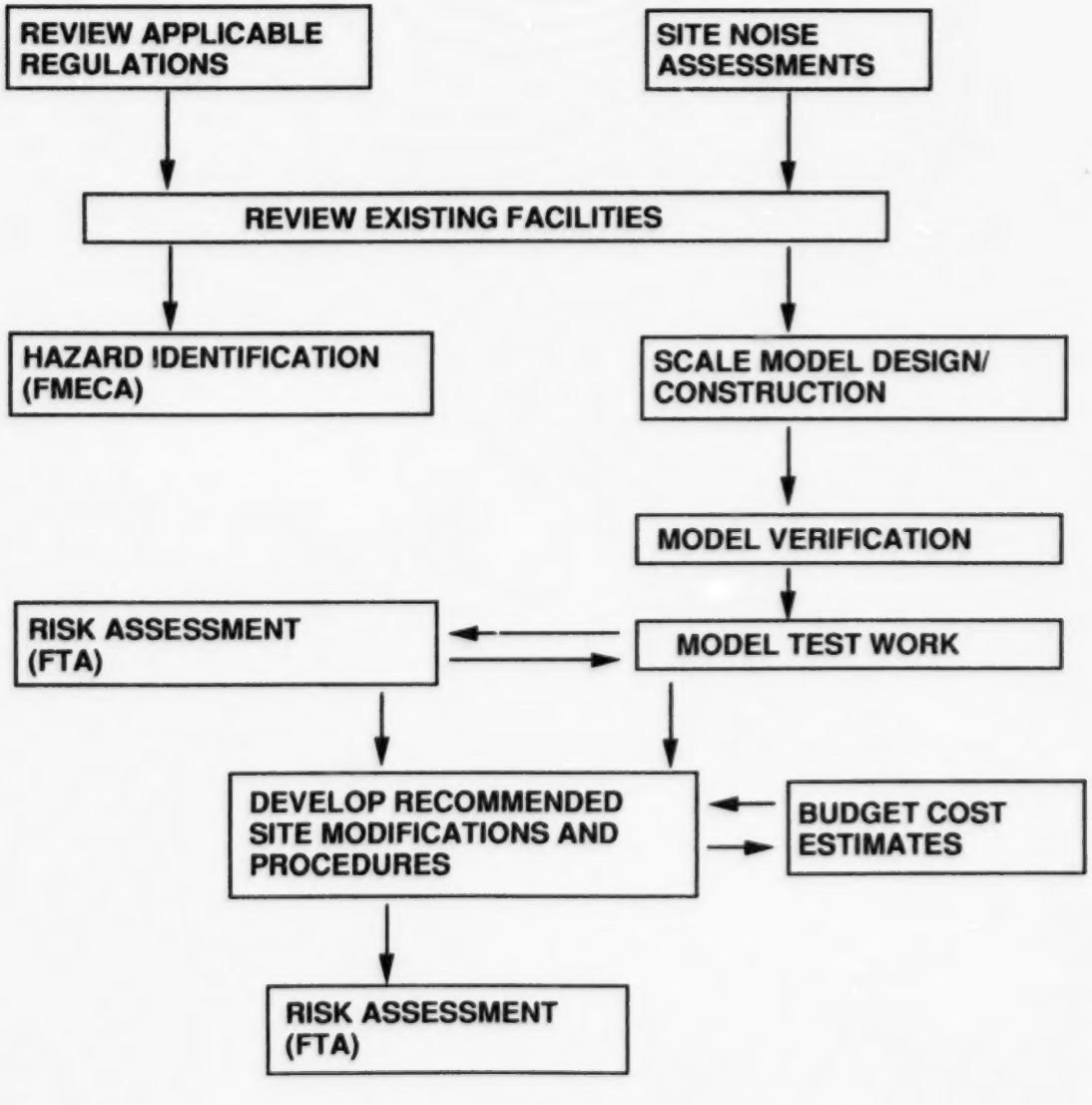


GARAGE

Scope of Project

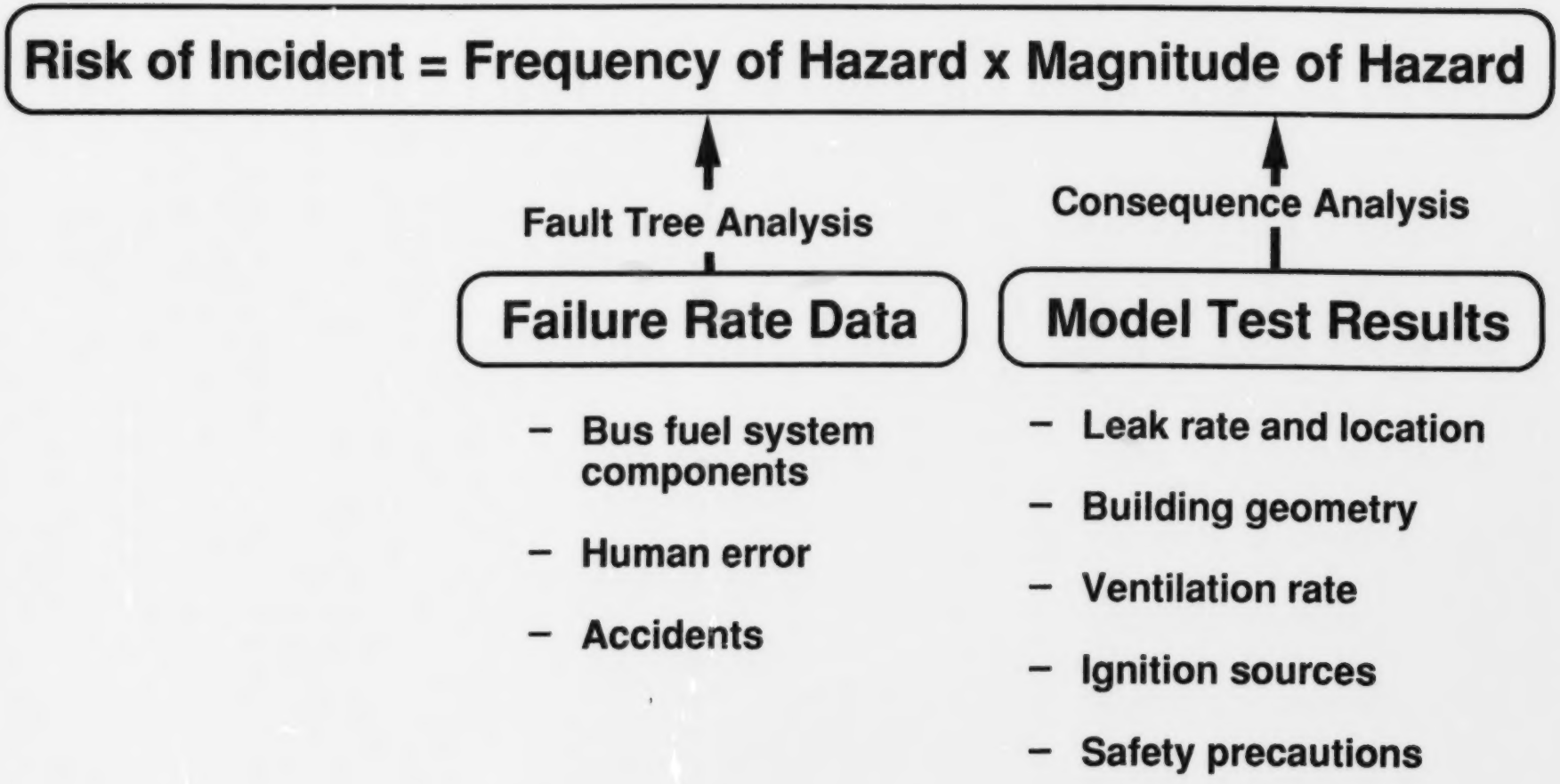
- Review of existing bus garages and operations (TTC Wilson garage, HSR Mountain garage and MT Central Parkway garage), applicable codes, accident records and NGV bus design
- Hazard identification
- Noise impact study
- Physical modelling and testing of each garage with respect to consequences of indoor NGV releases under a spectrum of conditions
- Risk assessment
- Development of recommended site modifications and procedures
- Cost estimation

Project Methodology



Characteristics of Existing Bus Garages

- Relatively low ventilation rates (0.52 FPS ~ 1.02 FPS cross drafts)
- Open flame unit heaters
- Non-hazardous electrical classification
- Open and closed roof truss structures
- Carbon monoxide detection and ventilation control
- Superior fire extinguishing systems


Risk of Incident = Frequency of Hazard x Magnitude of Hazard
Fault Tree Analysis
Consequence Analysis
Failure Rate Data
Model Test Results
– Bus fuel system components
– Human error
– Accidents
– Leak rate and location
– Building geometry
– Ventilation rate
– Ignition sources
– Safety precautions

The Model Study

Objective:

- To relate leak profiles to local concentrations (compare to combustion limits)

Method:

- Small scale flow modelling
- Model overall flow/ventilation
- Model natural gas source
  - volume flow rate
  - buoyancy "flow" rate
  - release profile

Major Leak Source

- cylinder and line leaks
- engine compartment leaks
- filling port leaks

The Model Study (cont'd)

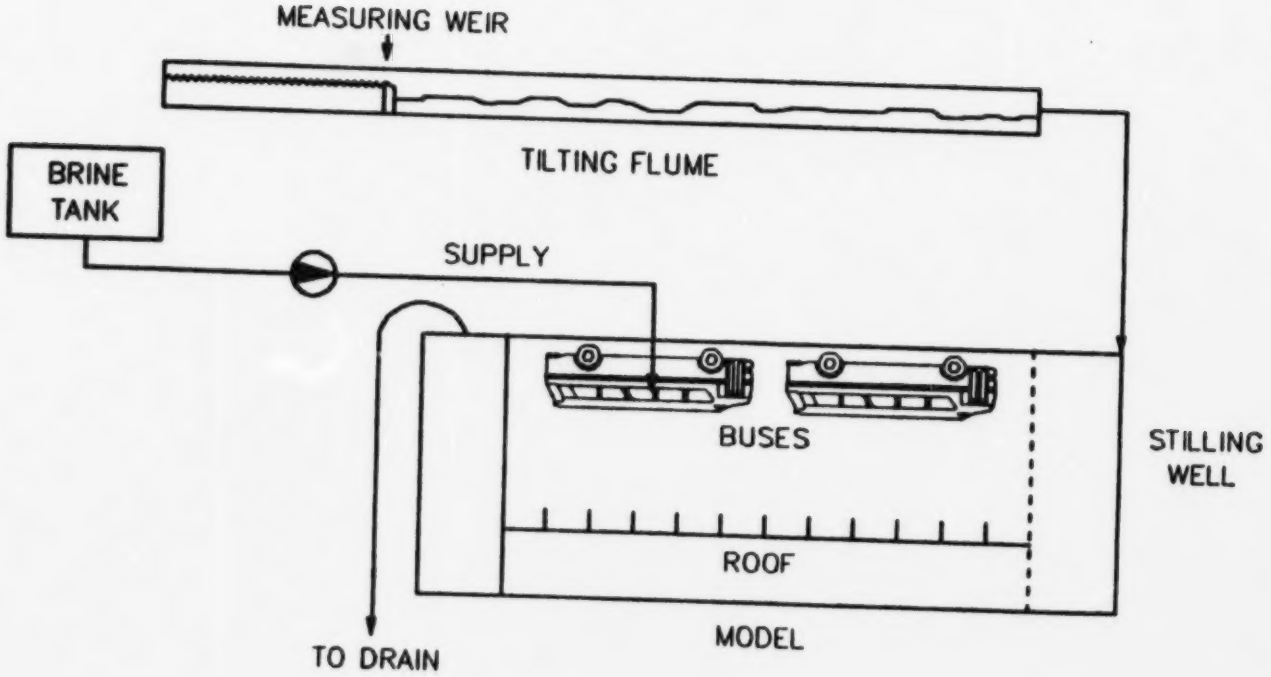
Approach:

- 15:1 scale model
- Water representing air
- Brine representing natural gas
- 3 buses wide x 2 buses deep

Testing Program

- Set bus configuration
- Set ventilation field
- Track concentration profile
- Record results

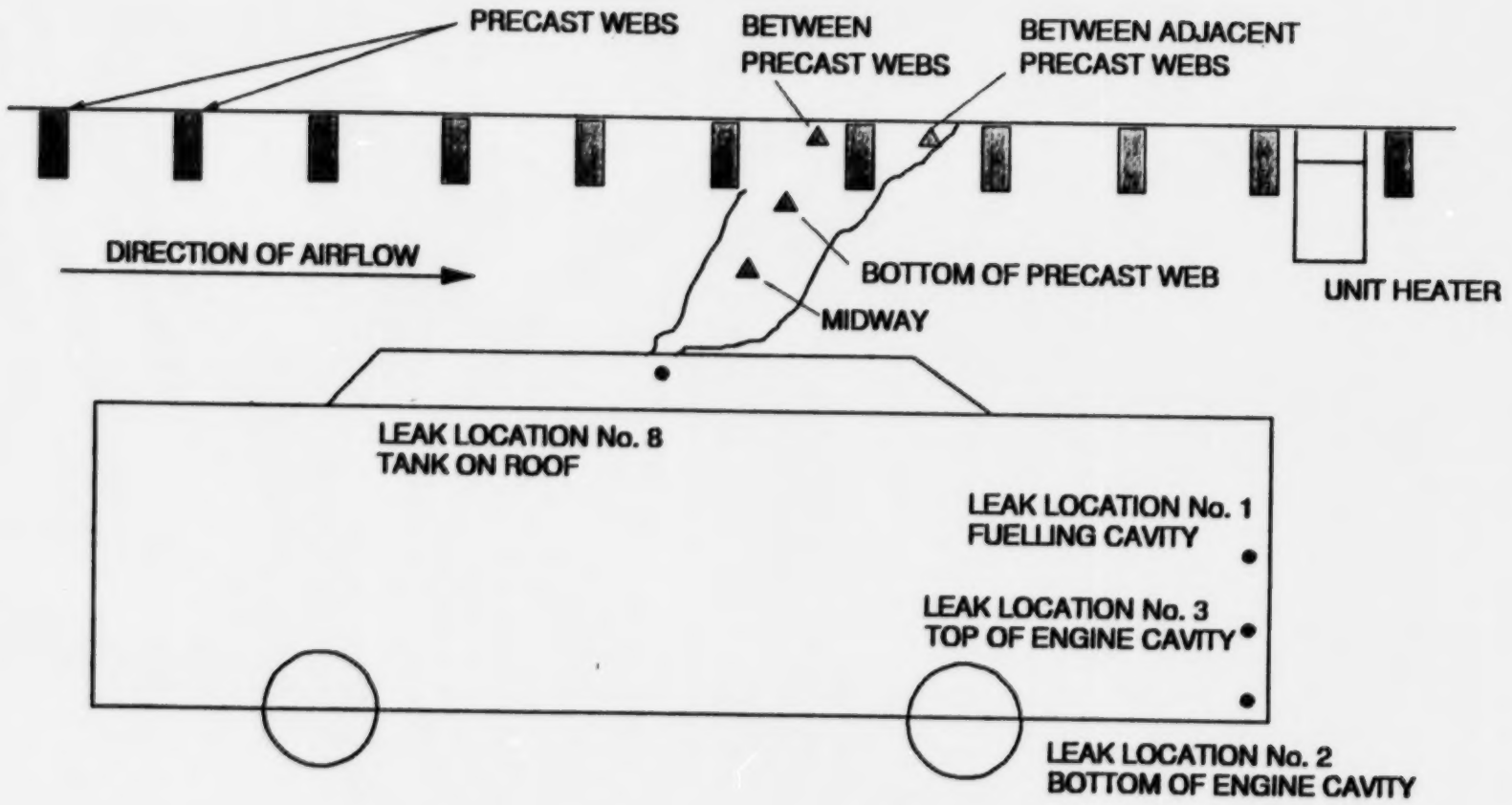
MODEL CONSTRUCTION



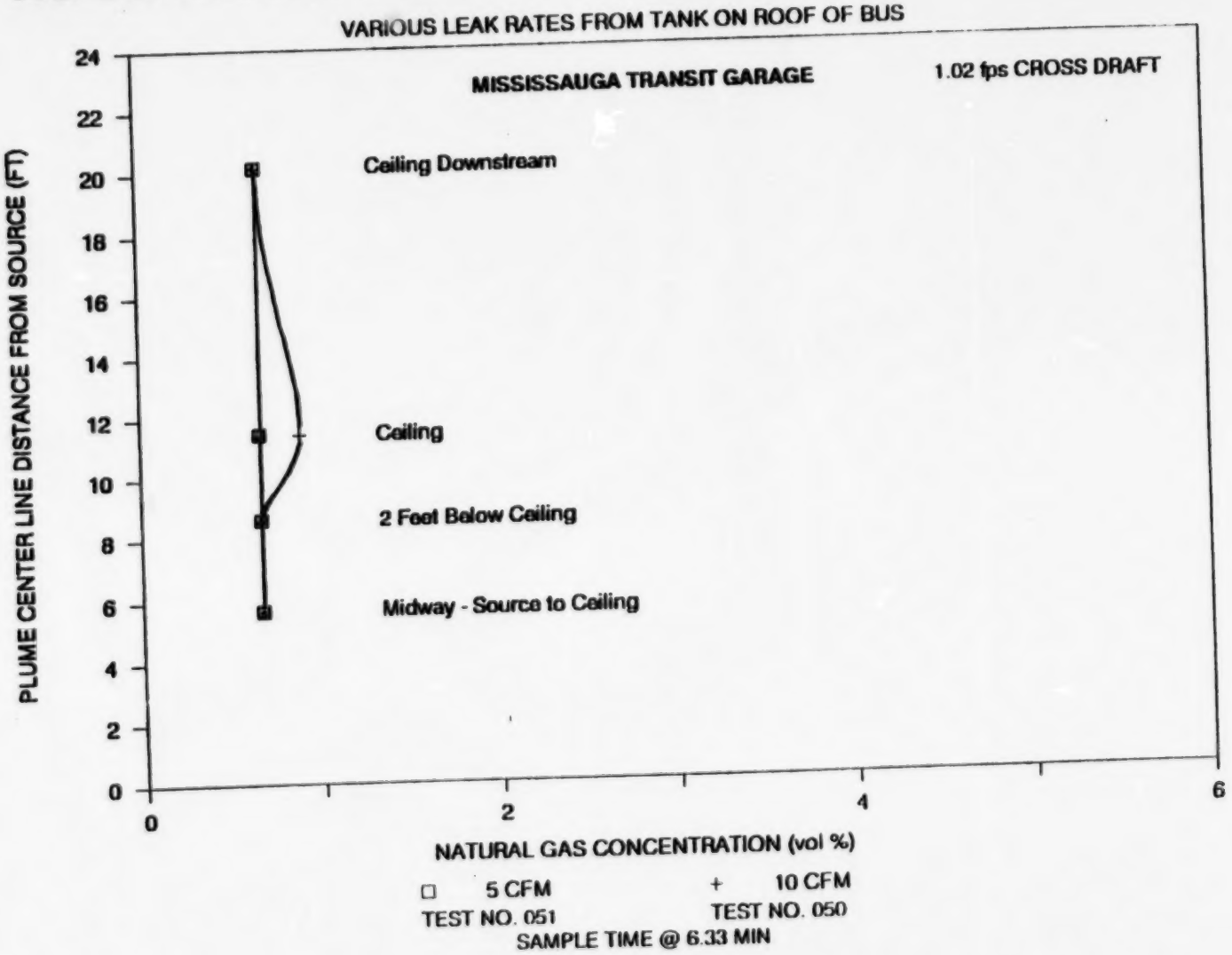
Variables Tested in Model Study

- Natural gas leak location on the bus
- Natural gas leakage rates
- Building ventilation schemes
- Building ventilation flow rates
- Building geometry

SKETCH OF TESTED LEAK LOCATIONS
TTC - WILSON GARAGE

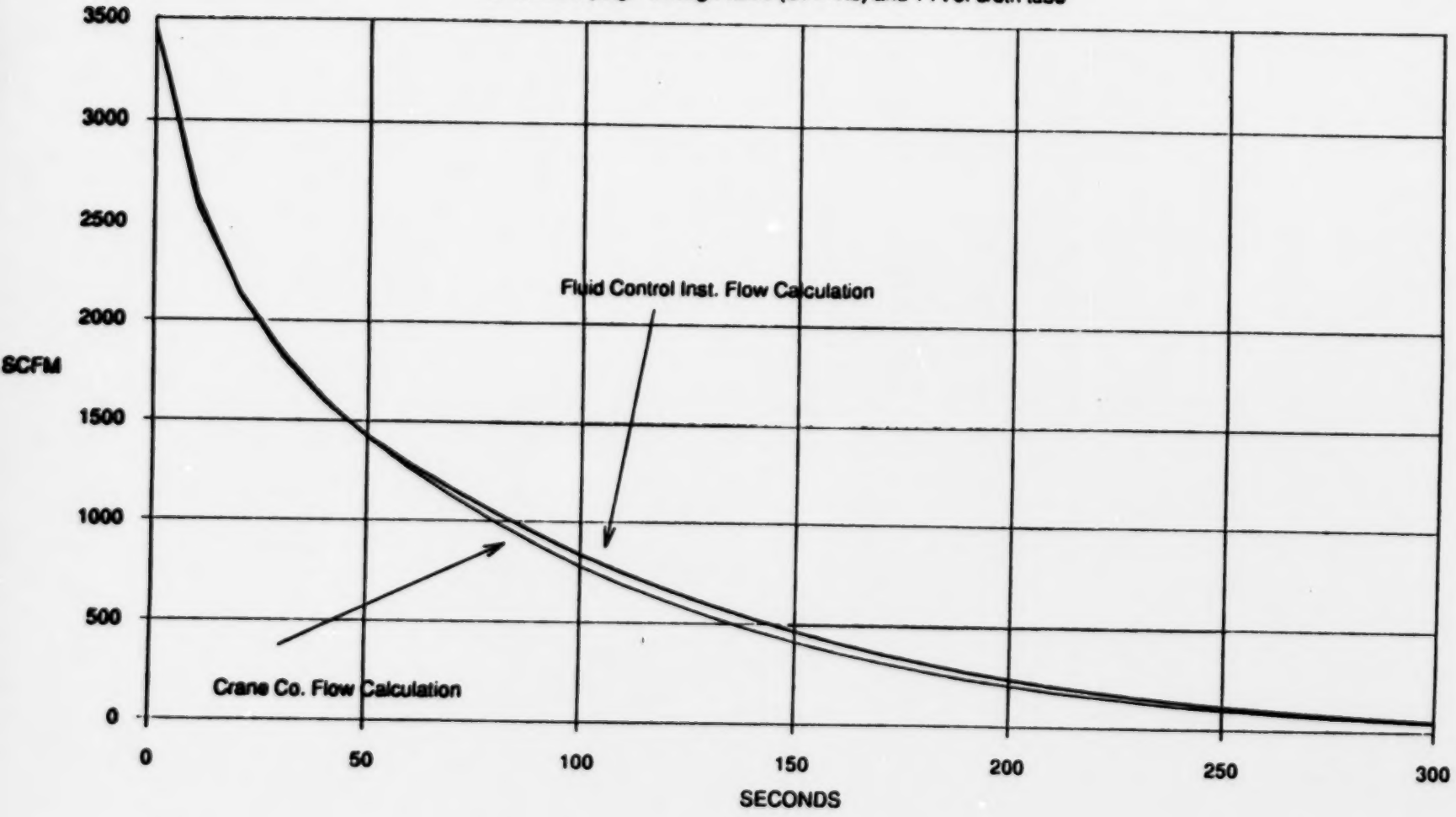


NG CONCENTRATION VS PLUME CENTER LINE DISTANCE

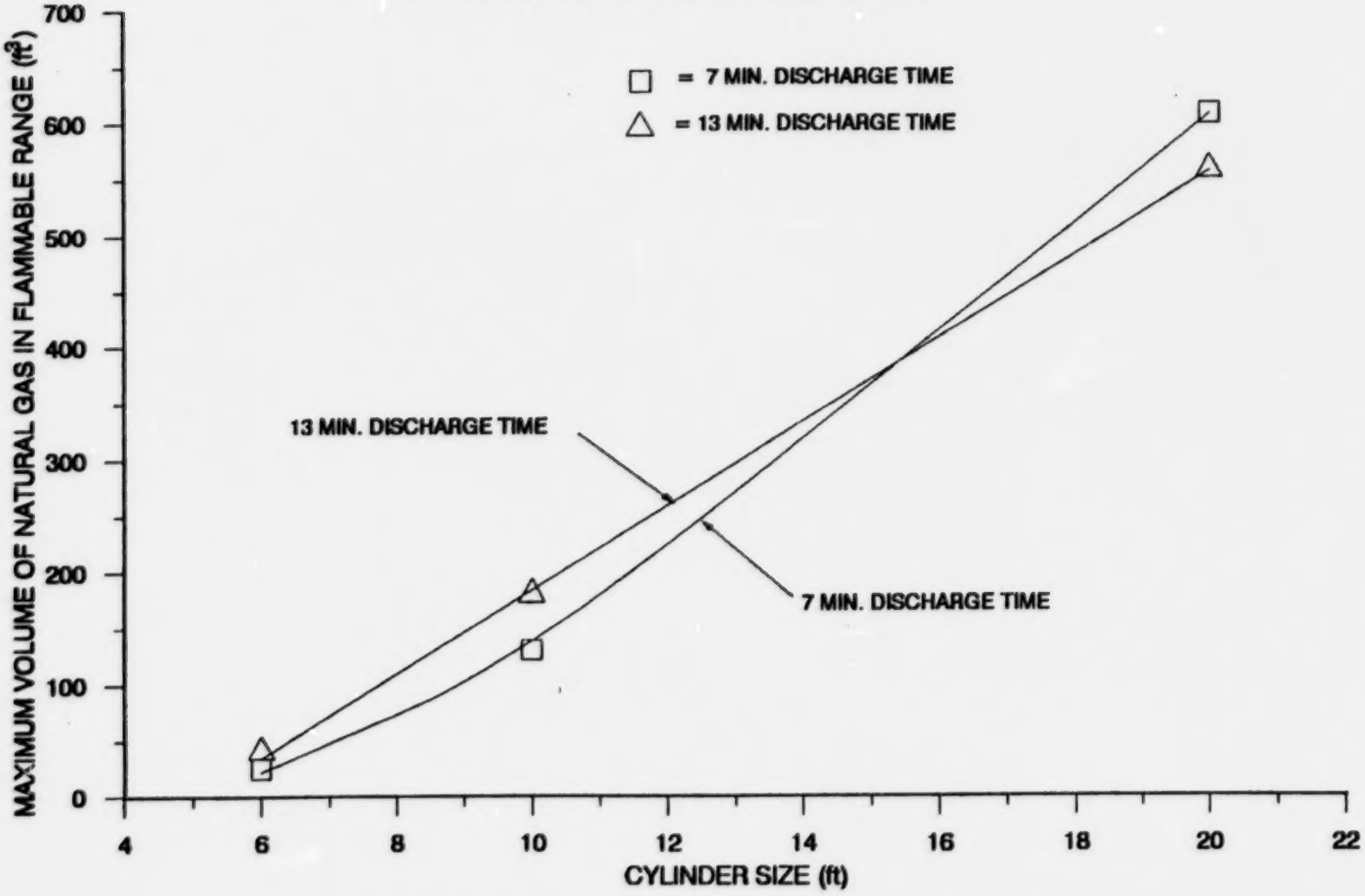


DISCHARGE OF NATURAL GAS CYLINDER

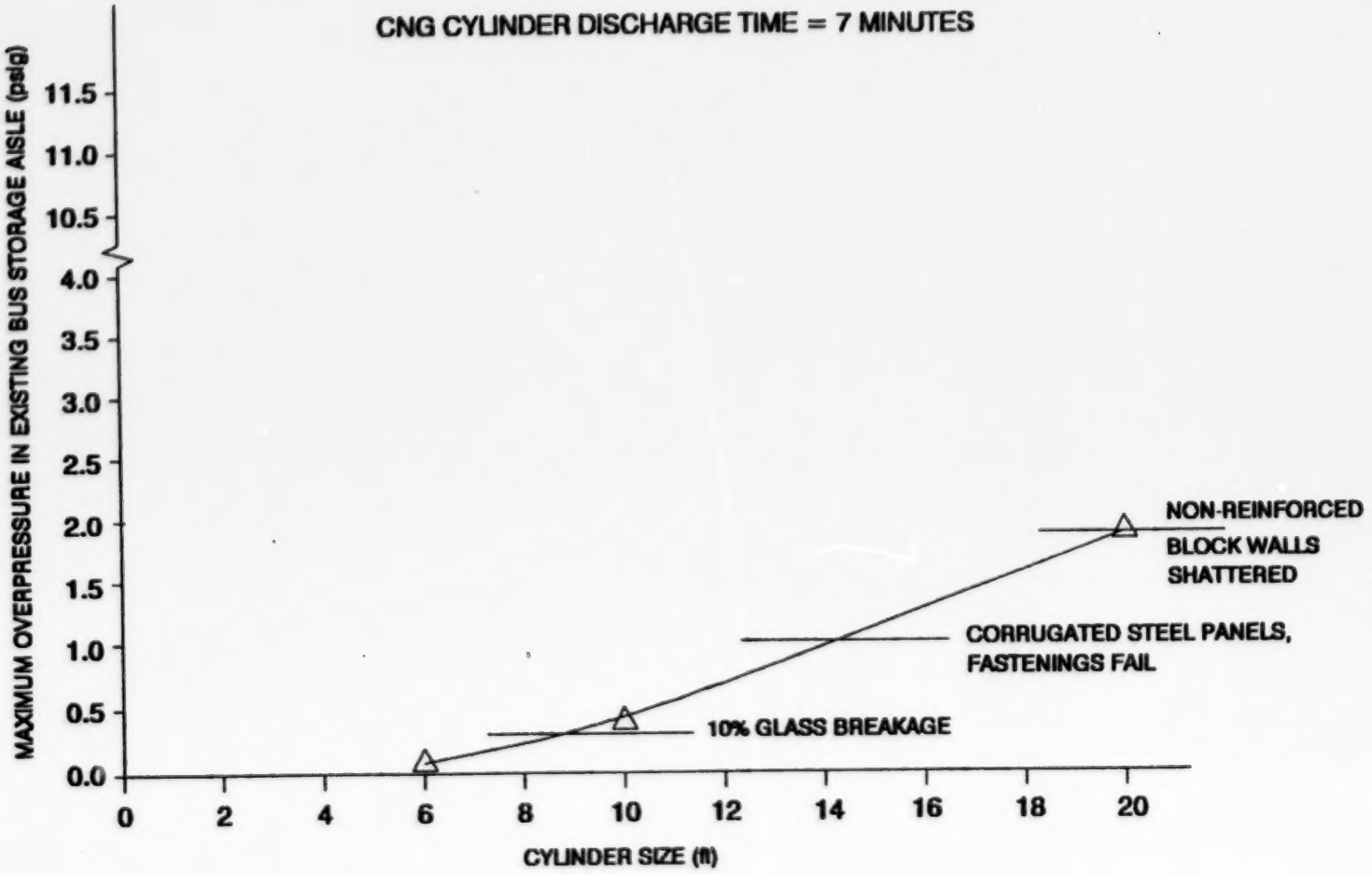
407 L, 3000 psig, through valve (Cv = 1.5) and 1 Ft of 3/8th tube



TTC WILSON GARAGE - MODIFIED VENTILATION
(VENTILATION RATE = 1.3 CFM/ft²)



TTC WILSON GARAGE - MODIFIED VENTILATION
(VENTILATION RATE = 1.3 cfm/ft^2)



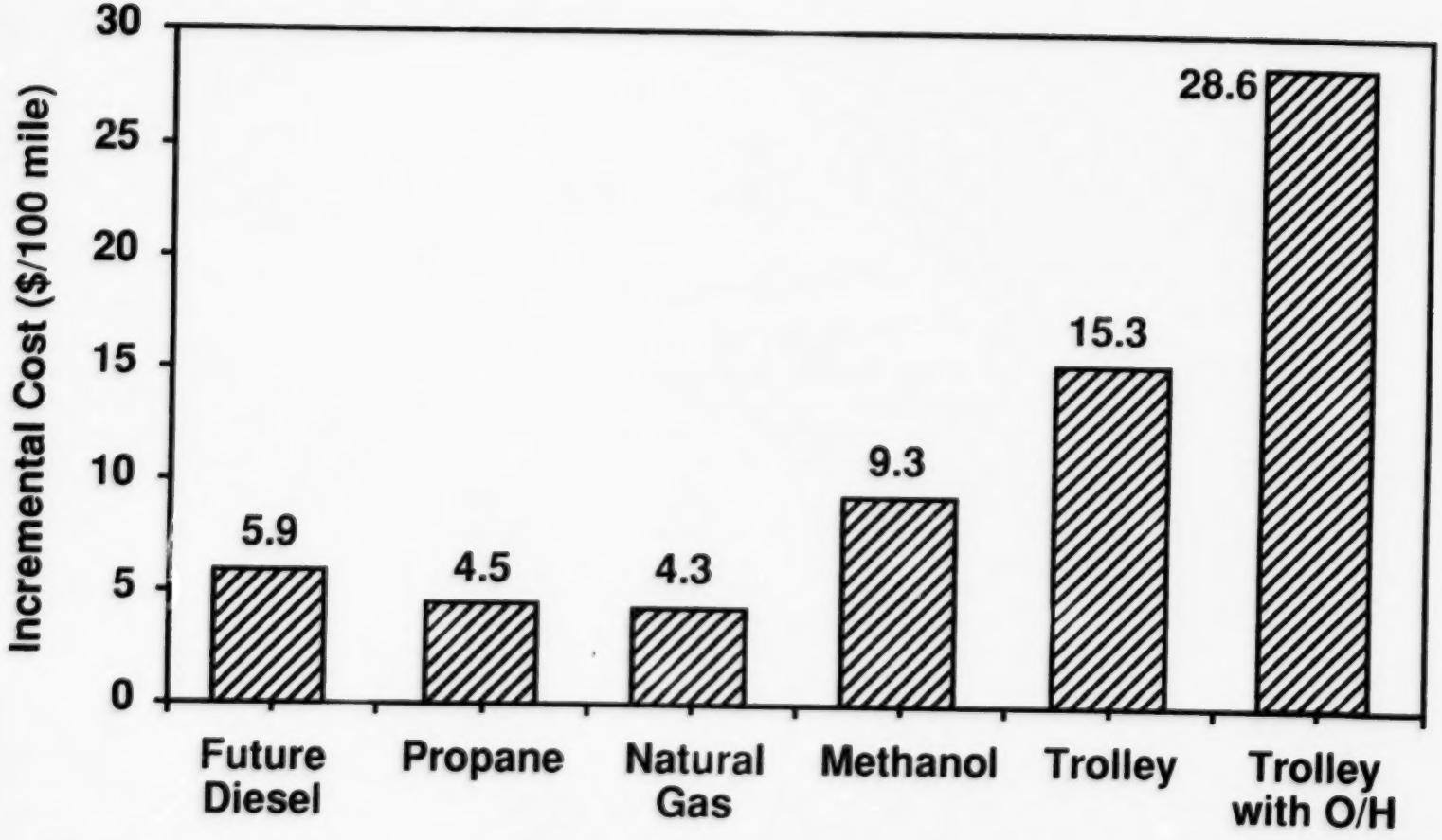
Proposed Improvements

- Higher ventilation rates
- New ventilation schemes (updraft, mixing, two-level)
- Indirect heaters
- Spark-proof electrical systems
- Leak detection and warning systems

Life-Cycle Cost Analysis

- Assessment of the Net Present Value of all incremental costs associated with the purchase and operation of alternative fuel buses
- Cost components explicitly considered:
  - Fuel or energy price
  - Bus capital cost
  - Fuelling equipment capital cost
  - Garage modification cost
  - Bus maintenance and inspection cost
  - Fuelling equipment maintenance cost
  - Garage maintenance cost
- Baseline conditions of the study
  - 1989 diesel bus constitutes the baseline
  - Modern 250 bus garage
  - Current technologies (1989-1991 time-frame)
  - Current transit operational practices
  - 5% discount rate

Life-Cycle Cost Increment
(Relative to 1989 Diesel)



Conclusions

- NG promises significant environmental and economic advantages
- The Ontario NGV bus program is progressing successfully towards a full-scale demonstration
- NGV buses, fuelling stations and garages can meet transit industry expectations with careful planning and engineering